9 Changes in Open Space and Vegetation

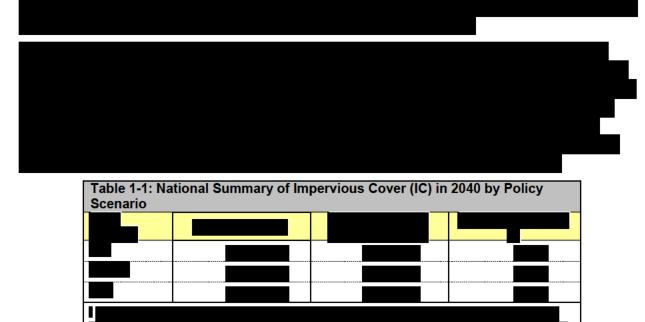
Stormwater management practices that use vegetated areas to filter and slow stormwater runoff provide both direct stormwater management benefits for receiving waters, and ancillary land-based benefits from increasing vegetative cover and open space. Relative to conventional development practices, the ancillary benefits of vegetation-based practices include ecosystem services like improved upland wildlife habitat, air pollution removal, greenhouse gas mitigation, heat island mitigation, enhanced property values, aesthetic improvements, and others (Chapter X provides more detail).

EPA projects that the three policy scenarios described in Chapter X will increase vegetation as development sites are redesigned to replace impervious cover with vegetated areas. EPA analyzed two pathways by which increasing vegetation levels in developed areas can reduce ambient concentrations of criteria air pollutants: directly, by removing pollutants from the air, and indirectly, by reducing air emissions associated with energy use for cooling and heating buildings.

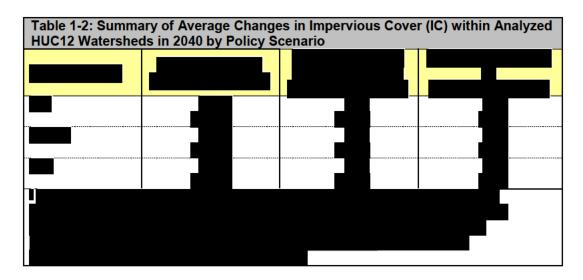
The level of atmospheric pollutant removal services provided by vegetation under the three policy scenarios depends in part on the nature and amount of additional vegetation beyond baseline conditions expected under each of the policy scenarios. This Chapter describes the data, methodology, and assumptions that EPA used to quantify changes in vegetation for its analysis of air pollution removal services and its carbon sequestration analysis.

9.1 Estimate Changes in Vegetation

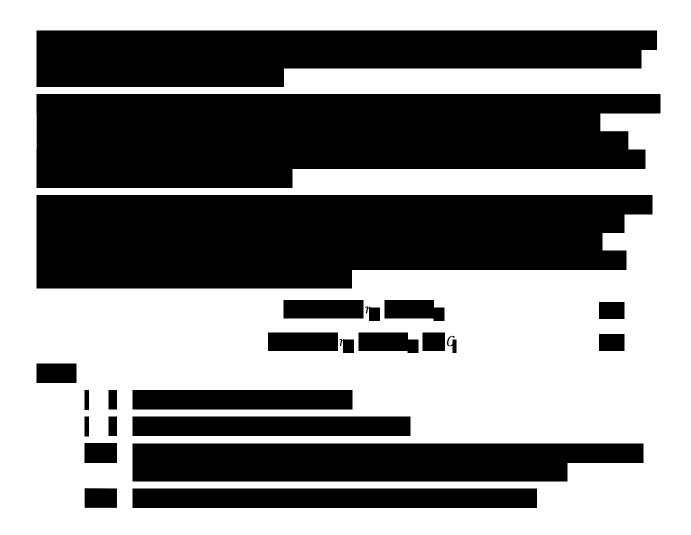
EPA's analysis of benefits from an increase in vegetative cover focuses on development projects managing stormwater through the use of site redesign to replace impervious surfaces with vegetated areas.











10 Carbon Sequestration

Climate change is widely viewed to be a significant long-term threat to the global environment. Carbon dioxide (CO_2) and other greenhouse gases (e.g., CH_4 and N_2O) contribute to climate change by absorbing outgoing terrestrial radiation (Jo & McPherson, 2001; U.S. EPA, 2010). EPA projects that the three policy scenarios described in Chapter X will increase vegetation as development sites are redesigned to replace impervious cover with vegetated areas. EPA analyzed how increasing vegetation levels in developed areas can reduce atmospheric carbon (C) in two ways: directly, by sequestering and storing carbon and indirectly, by reducing building energy use (Akbari & Konopacki, 2003; Jo & McPherson, 1995).

Trees and other vegetation sequester carbon in their biomass or in the soil, removing it from the atmosphere and preventing it from contributing to climate change. EPA quantified the amount of carbon sequestered annually by trees and grass by applying values for carbon sequestration per unit area to the amount of additional vegetation in each year of the analysis.

This chapter focuses on the economic benefits of greenhouse gas mitigation from carbon sequestration by vegetation. EPA monetized the economic benefits of sequestration based on the social cost of carbon (SCC) (Interagency Working Group, 2013). First it describes EPA's method for quantifying changes in vegetation under the policy options, then describes the calculation of net changes in sequestration and estimation of monetary benefits. Chapter X of this report presents EPA's analysis of reduced greenhouse gas emissions resulting from changes in energy consumption for cooling and heating due to shade trees.

10.1 Methodology

EPA's analysis of carbon sequestration under the three policy scenarios has three main steps:

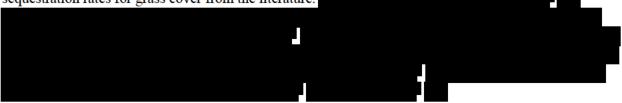
- 1. Estimate changes in vegetation under policy scenarios considered (Chapter 1);
- 2. Estimate net changes in carbon sequestration; and
- 3. Estimate monetary benefits based on SCC.

See Chapter X for descriptions of the estimates of future development, associated stormwater control practices, and the three policy scenarios that EPA used to inform this benefits analysis.

10.1.1 Net Changes in Carbon Sequestration Services



Above-ground herbaceous biomass tends to die annually unlike the woody portions of plants which can store carbon for many years prior to dying and decomposing (Gorte, 2009). Carbon accumulates in the upper soil layers as dead vegetation is added to the surface and decomposes. Carbon can also be injected into the soil through root biomass growth and decomposition. Table 1-4 summarizes annual net carbon sequestration rates for grass cover from the literature.



Grasses have been shown to sequester carbon over long periods of time, up to 45 years, with rates greatest in the first 25 to 30 years after establishment of grass cover (W. M. Post & Kwon, 2000; Pouyat, Yesilonis, & Golubiewski, 2009; Qian & Follett, 2002).

Table 1-1: Summary of Annual Grass Net Carbon Sequestration Rates from the Literature				
	<u> </u>			





10.1.2 Estimation of Carbon Sequestration Benefits under Policy scenarios

"SCC is an estimate of the monetized damages associated with an incremental increase in carbon emissions in a given year" (Interagency

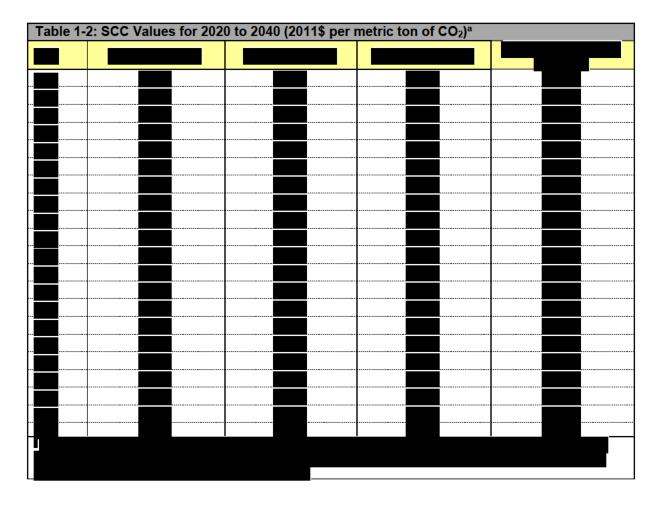
Working Group, 2013, p.2). SCC intends to reflect the value of the various effects of climate change, such as changes in net agricultural productivity, human health, property damages from increased flood risk, and the value of ecosystem services affected by climate change. It is typically expressed as dollars per metric ton of carbon dioxide (CO₂) removed from the atmosphere or alternatively as dollars per metric ton of carbon (C). SCC increases over time as incremental damages associated with CO2 emissions grow (IWG, 2010, 2013).

The economic literature includes many SCC values estimated using various models and assumptions. SCC is often estimated based on outputs from integrated assessment models (IAMs) which tie climate changes to economic damages. Beginning in 2009, EPA has participated in a U.S. Government Interagency Working Group to develop SCC values for use in regulatory analysis (IWG, 2010). ⁴ The working group developed a set of recommended SCC values for use in U.S. regulatory analyses based on the average from original runs of three IAMs - the Dynamic Integrated Climate and Economy model (DICE), the Policy Analysis of the Greenhouse Effects model (PAGE), and the Climate Framework for Uncertainty, Negotiation, and Distribution (FUND) model (IWG, 2010). A technical update to the SCC values was released in 2013 (IWG, 2010).

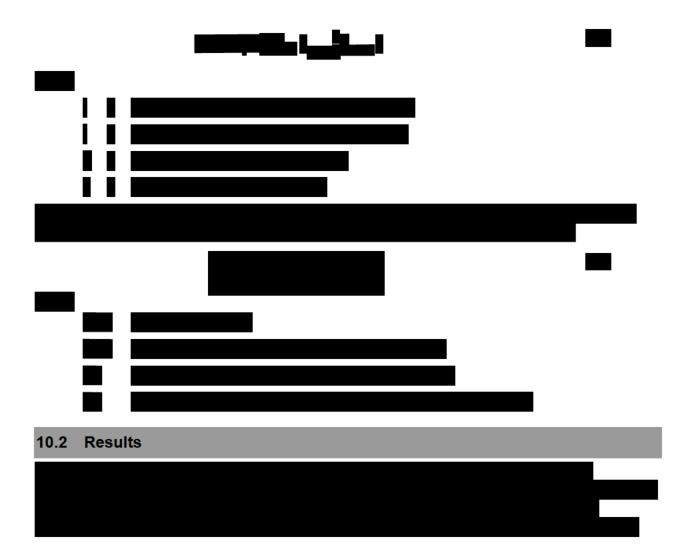
The discounting of SCC values requires special consideration because of the discount rate assumptions included within their estimation. That is, an SCC value estimated for a given year reflects costs in later years which are discounted back to the year when the CO₂ is emitted. The Interagency Working Group selected four sets of SCC values for use in regulatory analysis, using 2.5 percent, 3 percent, and 5 percent discount rates. The fourth set of SCC values reflects the 95th percentile SCC values across all models using a 3 percent discount rate.

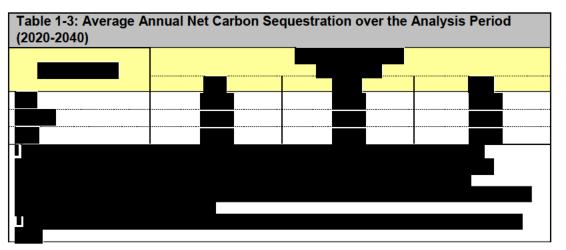
Other participants include the Council of Economic Advisers, Council on Environmental Quality, Department of Agriculture, Department of Commerce, Department of Energy, Department of Transportation, National Economic Council, Office of Energy and Climate Change, Office of Management and Budget, Office of Science and Technology Policy, and the Department of the Treasury.

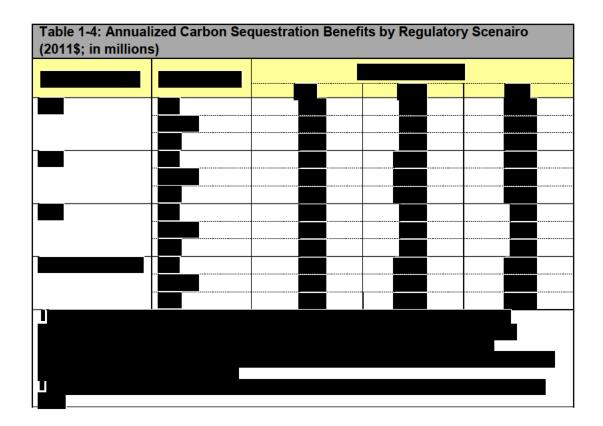
Some analysts of SCC have included "equity weights" to account for differences in consumption and relative reductions in wealth across different regions of the world. The argument is that a monetary loss in a poor county results in a greater loss of utility than the same amount of money in a wealthy country. The Interagency Working Group concluded that this approach is not appropriate when estimating SCC values for domestic regulations (IWG, 2010),





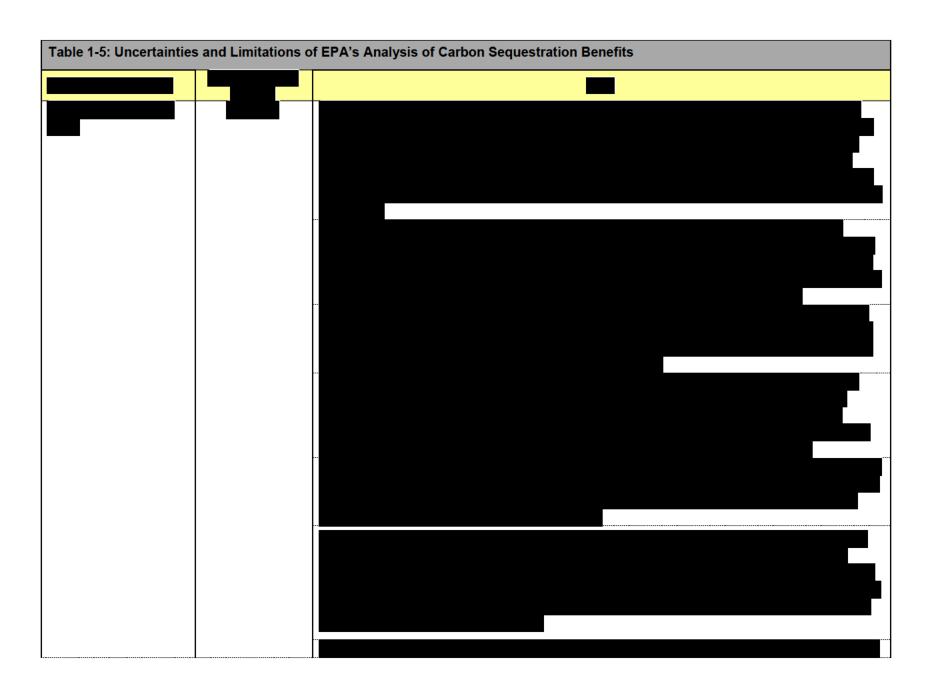


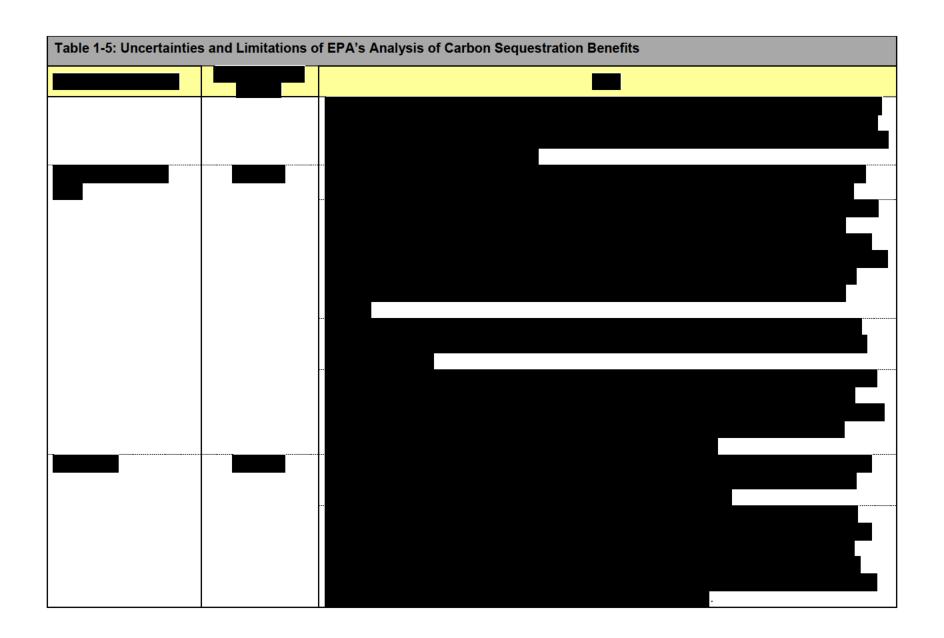




10.3 Uncertainty and Limitations

Uncertainty and limitations inherent in EPA's methodology are described below in Table 1-8.





10.4 References

- Akbari, H., & Konopacki, S. J. (2003). Streamlined energy-savings calculations for heat-island reduction strategies.
- Andrews, C. J. (2008). Greenhouse gas emissions along the rural-urban gradient. *Journal of Environmental Planning and Management*, 51(6), 847-870.
- Bandaranayake, W., Qian, Y. L., Parton, W. J., Ojima, D. S., & Follett, R. F. (2003). Estimation of Soil Organic Carbon Changes in Turfgrass Systems Using the CENTURY Model. *Agronomy Journal*, 95(3), 558-563.
- Bruce, J. P., Frome, M., Haites, E., Janzen, H., Lal, R., & Paustian, K. (1999). Carbon sequestration in soils. *Journal of Soil and Water Conservation*, *54*(1), 382-389.
- Burke, I. C., Lauenroth, W. K., & Coffin, D. P. (1995). Soil Organic Matter Recovery in Semiarid Grasslands: Implications for the Conservation Reserve Program. *Ecological Applications*, *5*(3), 793-801.
- Conant, R. T., Paustian, K., & Elliott, E. T. (2001). Grassland Management and Conversion into Grassland: Effects on Soil Carbon. *Ecological Applications*, 11(2), 343-355.
- Gebhart, D. L., Johnson, H. B., Mayeux, H. S., & Polley, H. W. (1994). The CRP increases soil organic carbon. *Journal of Soil and Water Conservation*, 49(5), 488-492.
- Gorte, R. W. (2009). Carbon Sequestration in Forests. Congressional Research Service (CRS) report to Congress, 7-5700, August 6, 2009.
- Interagency Working Group (IWG). (2010). Technical Support Document Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866: Interagency Working Group on Social Cost of Carbon, United States Government, with participation by Council of Economic Advisors, Council on Environmental Quality, Department of Agriculture, Department of Commerce, Department of Energy, Department of Transportation, Environmental Protection Agency, National Economic Council, Office of Energy and Climate Change, Office of Management and Budget, Office of Science and Technology Policy, Department of the Treasury.
- Interagency Working Group. (2013). Techincal Support Document- Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866: Interagency Working Group on Social Cost of Carbon, United States Government, with participation by Council of Economic Advisors, Council on Environmental Quality, Department of Agriculture, Department of Commerce, Department of Energy, Department of Transportation, Environmental Protection Agency, National Economic Counicl, Office of Management and Budget, Office of Science and Technology Policy, Department of the Treasury.
- Jo, H. K., & McPherson, E. G. (2001). Indirect carbon reduction by residential vegetation and plating strategies in Chicago, USA. *Journal of Environmental Management*, 61, 165-177.
- Jo, H. K., & McPherson, G. E. (1995). Carbon storage and flux in urban residential greenspace. *Journal of Environmental Management*, 45(2), 109-133.
- MillionTreesNYC. (2011). About MillionTreesNYC: NYC Tree Facts Retrieved January, 2012, from http://www.milliontreesnyc.org/html/about/urban forest facts.shtml
- Nowak, D. J., & Greenfield, E. J. (2010). Evaluating the National Land Cover Database tree canopy and impervious cover estimates across the conterminous United States: a comparison with photo-interpreted estimates. *Environmental Management*, 46(3), 378-390.
- Nowak, D. J., Greenfield, E. J., Hoehn, R. E., & Lapoint, E. (2013). Carbon storage and sequestration by trees in urban and community areas of the United States. *Environmental Pollution*, 178, 229-236.
- Pickett, S. T. A., Cadenasso, M. L., Grove, J. M., Groffman, P. M., Band, L. E., Boone, C. G., Burch Jr., W.R., Grimmond, S.B., Hom, J., Jenkins, J.C., Law, N.L, Nilon, C.H., Pouyat, R.V., Szlavecz, K., Warren, P.S., & Wilson, M. A. (2008). Beyond Urban Legends: An Emerging Framework of Urban Ecology, as Illustrated by the Baltimore Ecosystem Study. *BioScience*, 58(2), 139-150.
- Post, W. M., & Kwon, K. C. (2000). Soil carbon sequestration and land-use change: processes and potential. *Global Change Biology*, *6*(3), 317-327.

- Pouyat, R., Yesilonis, I., & Golubiewski, N. (2009). A comparison of soil organic carbon stocks between residential turf grass and native soil. *Urban Ecosystems*, 12(1), 45-62.
- Qian, Y. I., & Follett, R. F. (2002). Assessing Soil Carbon Sequestration in Turfgrass Systems Using Long-Term Soil Testing Data. *Agronomy Journal*, *94*, 930–935.
- Qian, Y. I., Follett, R. F., & Kimble, J. M. (2010). Soil Organic Carbon Input from Urban Turfgrasses. Soil Science Society of America Journal, 74(2), 366-371.
- Selhorst, A. L. (2007). Carbon sequestration and emissions due to golf course turfgrass development and maintenance in central Ohio. Master of Science Thesis, The Ohio State University, Columbus, OH
- Smith, M. L., Zhou, W., Cadenasso, M., Grove, M., & Band, L. E. (2010). Evaluation of the National Land Cover Database for Hydrologic Applications in Urban and Suburban Baltimore, Maryland. *Journal of the American Water Resources Association*, 46(2), 429-442.
- U.S. Bureau of Economic Analysis. (2012). Concepts and Methods of the U.S. National Income and Product Accounts. Chapters 1-20 and 13.
- U.S. EPA. (2010a). Guidelines for Preparing Economic Analysis. National Center for Environmental Economics, Office of Policy. December 17, 2010.
- U.S. EPA, U. S. D. O. T., National Highway Traffic Safety Administration,. (2010). *Light-Duty Vehicle Greenhouse Gas Emissions Standards and Corporate Average Fuel Economy Standards; Final Rule*. Federal Register Vol. 75 No. 88, 25,324-25,728, May 7, 2010.
- USFS. (2010). Publications & Data. Available at: http://www.nrs.fs.fed.us/pubs/.
- Zirkle, G., Lal, R., & Augustin, B. (2011). Modeling Carbon Sequestration in Home Lawns. *HortScience*, 46(5), 808-814.

11 Atmospheric Pollutant Removal

Vegetation can act as a sink for ambient pollutants through dry deposition onto the vegetation surface and through uptake through leaf stomata (Beckett, Freer-Smith, & Taylor, 2000; Nowak, Crane, & Stevens, 2006; Yang, Yu, & Gong, 2008; Nowak et al., 2013). "Dry deposition' describes the combined removal of particulate pollutants from the atmosphere by gravity, Brownian motion, impaction and direct interception" (Beckett, et al., 2000, p.996). Gaseous pollutants are primarily removed by uptake through leaf stomata and particulate pollutants are primarily removed by plant surfaces (Nowak, Crane, et al., 2006; Nowak, et al., 1998). Vegetation is typically only a temporary retention site for particulate pollutants. Intercepted particles are re-suspended into the atmosphere, washed off by precipitation, or deposited on the ground with leaves, twigs, and other plant debris (Nowak, et al., 1998). The mass of pollutant removed by vegetation tends to represent a small fraction of total ambient pollution (Nowak et al. 2006; Nowak et al. 2013). For example, annual percentage reductions in ambient PM2.5 range from 0.05 percent to 0.24 percent for 10 cities examined by Nowak et al. (2013). However, the human health benefits of even small percentage changes in air quality can be substantial (Nowak et al. 2013).

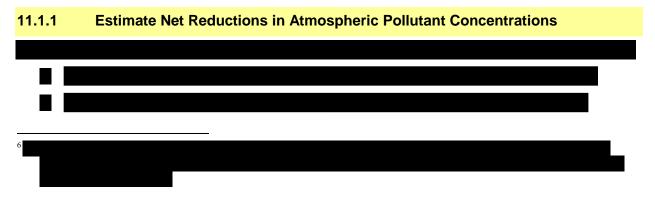
This chapter describes EPA's analysis of direct removal of pollutants.

11.1 Methodology

EPA's analysis of atmospheric pollutant removal due to the policy options has three main steps:

- 1. Estimate changes in vegetation under policy scenarios considered;
- 2. Estimate net reductions in atmospheric pollutant concentrations; and
- 3. Estimate human health benefits from reductions in pollution concentrations.

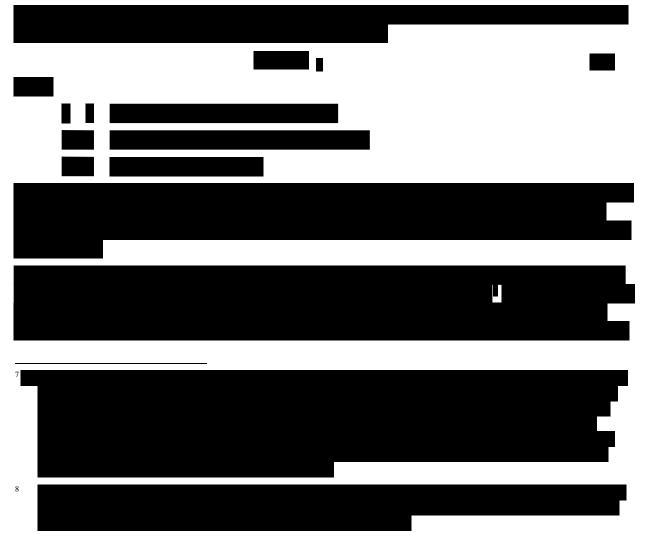
See Chapter X for descriptions of the estimates of future development, associated stormwater control practices, and the three policy scenarios that EPA used to inform this benefits analysis. See Chapter 1 for a description of EPA's method for estimating changes in vegetation.





The following subsections describe EPA's approach for estimating pollutant removal by tree canopy and grass, and estimating changes in pollutant removal and changes in ambient concentrations under policy scenarios.





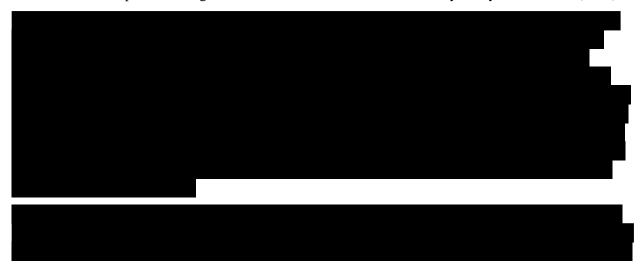
Abt Associates Inc. Draft – Internal - Deliberative

15



11.1.1.2 Tree Canopy Flux Rates for PM_{2.5}

The i-Tree Vue model does not currently include $PM_{2.5}$ flux rates, but USFS has recently published a methodology for estimating $PM_{2.5}$ flux and associated health benefits. The study estimates $PM_{2.5}$ flux rates, effect on ambient $PM_{2.5}$ concentrations, and human health effects for existing tree canopy in ten U.S. cities. It uses hourly weather data and data from the literature to incorporate the effects of windspeed and precipitation on the deposition and resuspension of $PM_{2.5}$. Table 2-1 presents flux rates, changes in concentration, and percent changes in concentrations for the ten cities analyzed by Nowak et al. (2013).



USFS derived the state pollutant flux rates in i-Tree Vue from a study of national pollutant removal by Nowak et al. (2006) for the year 1994. USFS adjusted the 1994 flux rates to 2000 based on average regional pollution concentrations from between 1994 and 2000. The i-Tree Vue manual (USFS, 2011) provides additional detail.

Table 2-1: Flux Rates and Calculated Deposition Velocities for Cities Analyzed by Nowak et al. (2013)				
City	Flux Rate (g m ⁻² yr ⁻¹)	Change in Concentrations	Percent Change in Concentrations	
Atlanta, GA	0.36	0.030	0.24%	
Baltimore, MD	0.24	0.010	0.09%	
Boston, MA	0.32	0.020	0.19%	
Chicago, IL	0.26	0.011	0.09%	
Los Angeles, CA	0.13	0.009	0.07%	
Minneapolis, MN	0.23	0.010	0.08%	
New York, NY	0.24	0.010	0.09%	
Philadelphia, PA	0.17	0.006	0.08%	
San Francisco, CA	0.29	0.006	0.05%	
Syracuse, CA	0.27	0.009	0.10%	
Source: Nowak et al.	(2013)			

11.1.1.3 Grass flux rates

vegetation types.

i-Tree Vue model and Nowak et al. (2013) do not provide pollutant flux rates for grass.

Yang et al. (2008) used a dry deposition model to estimate removal of SO₂, NO₂, PM₁₀, and O₃ by green roofs in Chicago that incorporate short grasses and deciduous trees in their design. To calculate deposition velocity, Yang et al. (2008) assigned resistance components for grass and deciduous trees using algorithms from the literature. Table 2-2 presents estimated flux rates from Yang et al. (2008) for these

The

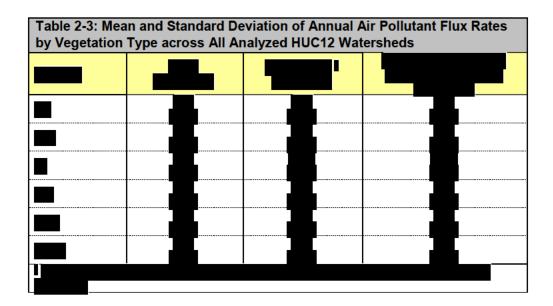
Table 2-2: Flux Rates Reported by Yang et al. (2008) by Vegetation Type (g/m²/yr) ^a				
Pollutant	Short Grass	Deciduous Trees		
SO ₂	0.65	1.01		
NO ₂	2.33	3.57		
PM ₁₀	1.12	2.16		
O ₃	4.49	7.17		
Total	8.59	13.91		
^a The study also estimated flux rates for herbaceous vegetation.				
Source: Yang et al. (2008)				

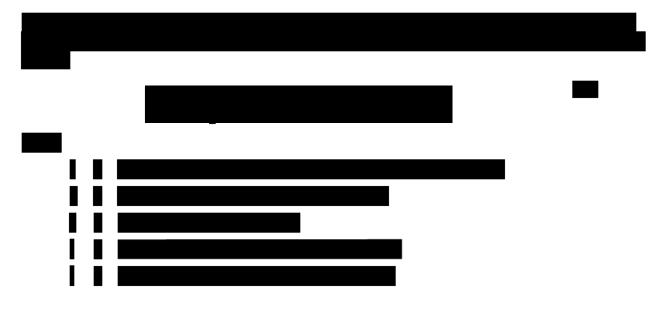
(2-2)



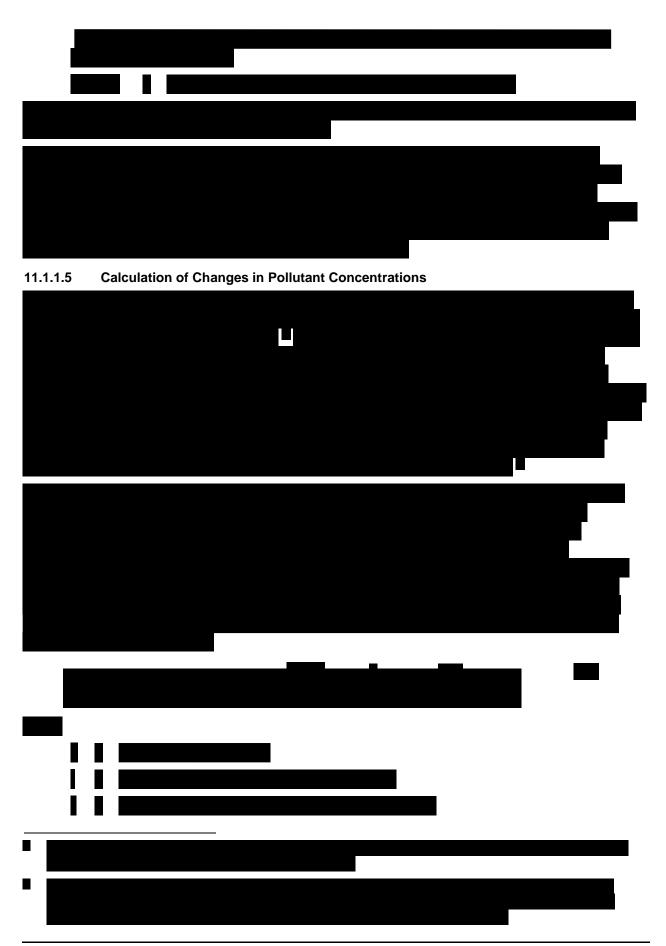
11.1.1.4 Calculation of Pollutant Removal under Policy Scenarios

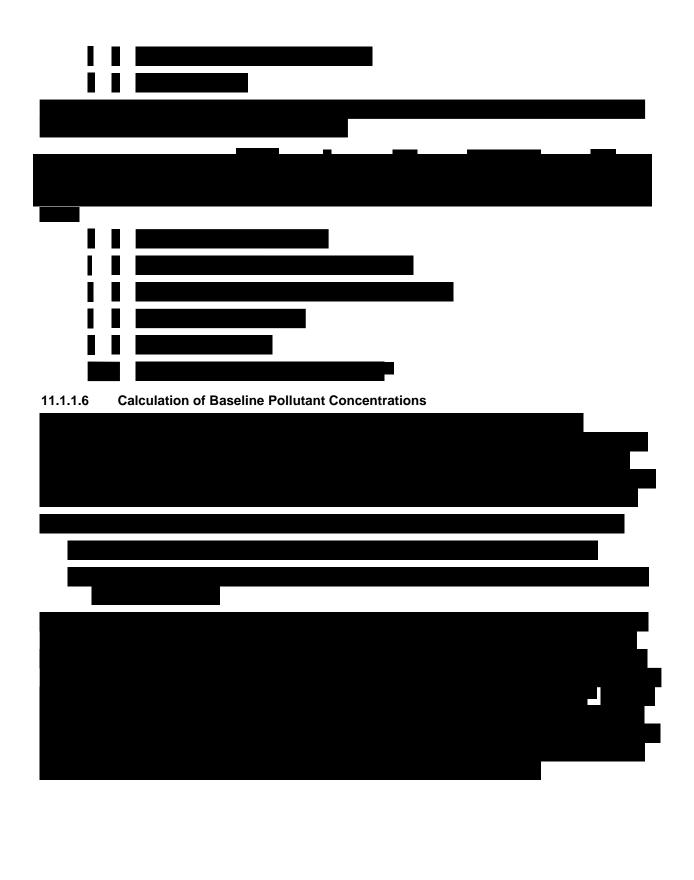


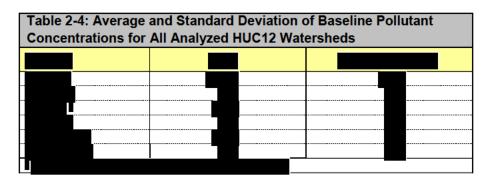


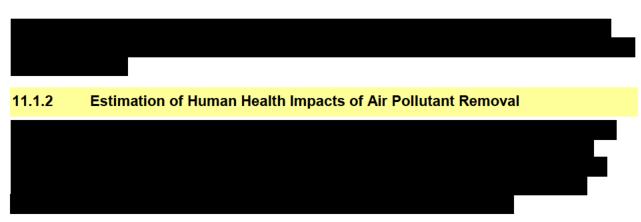


18







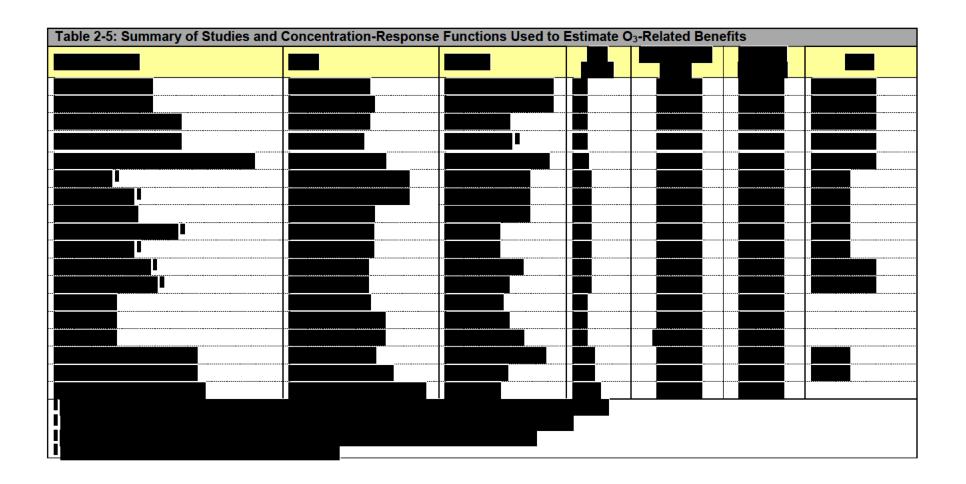




22

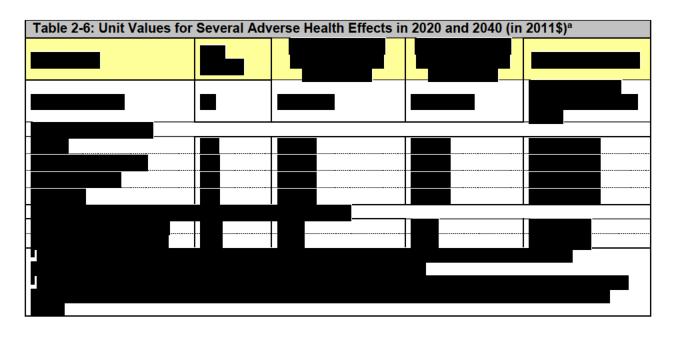


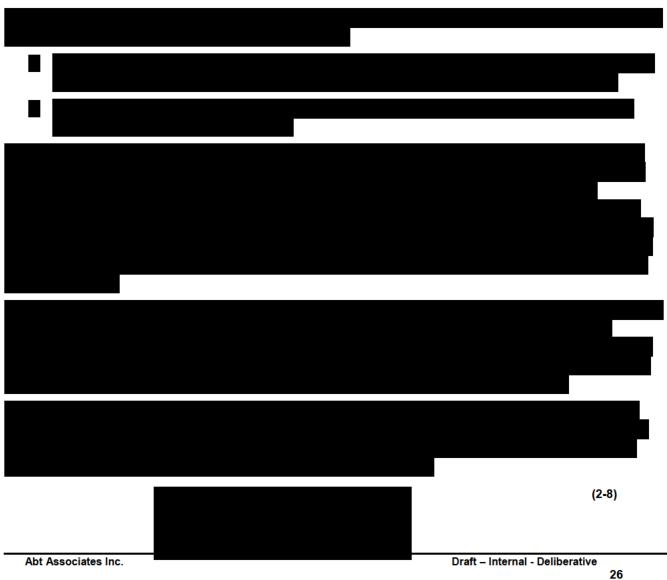
18

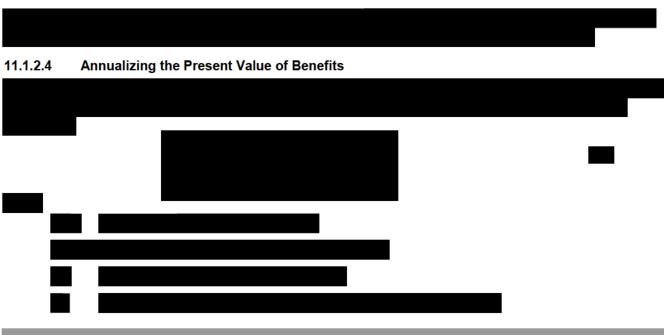


11.1.2.3 Valuing Avoided Cases of Adverse Health Effects

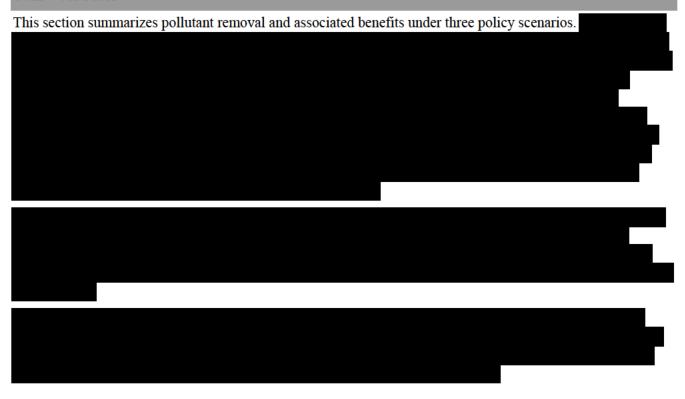


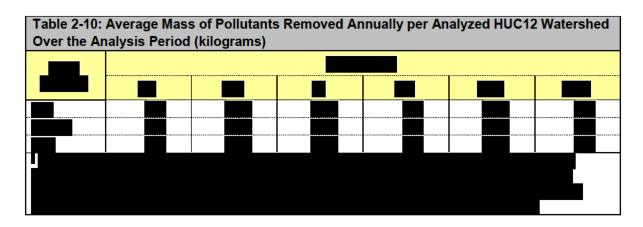


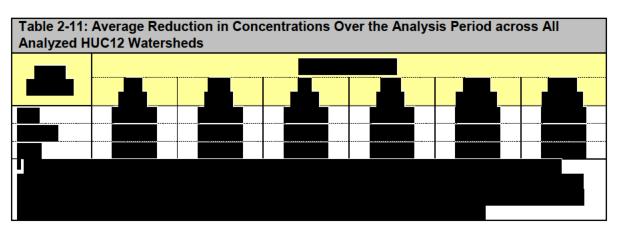


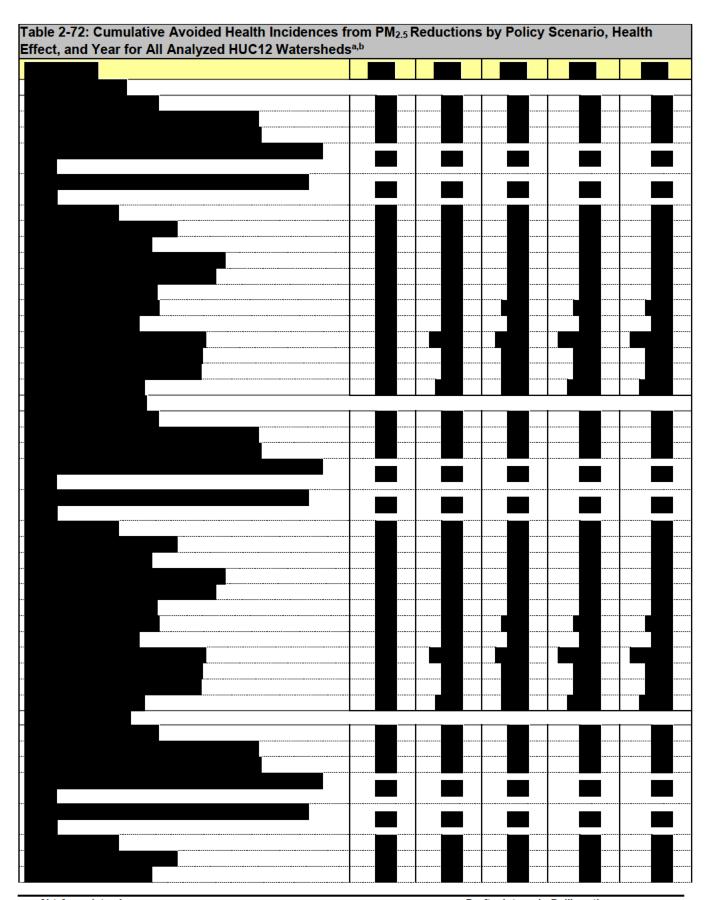


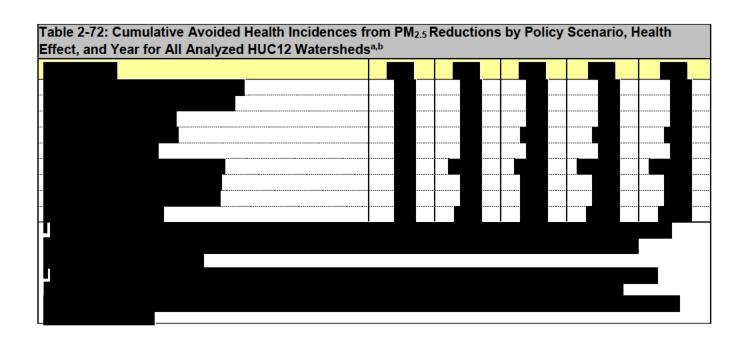
11.2 Results

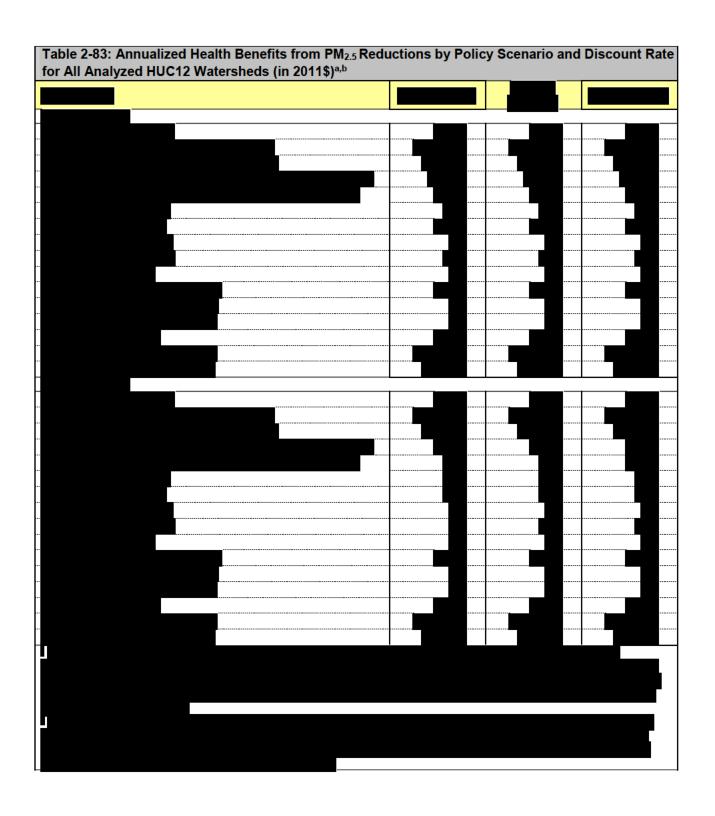


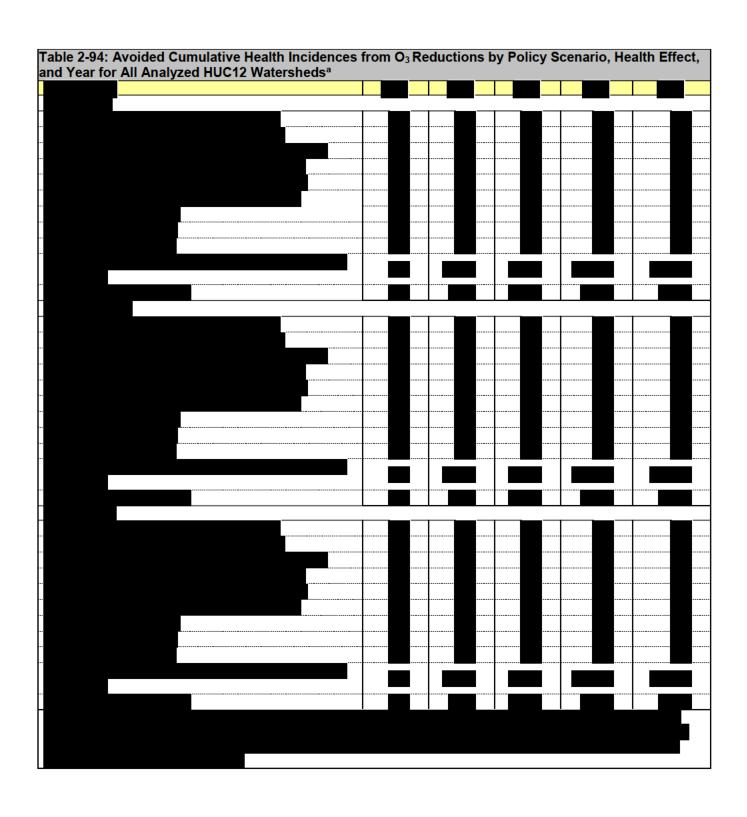


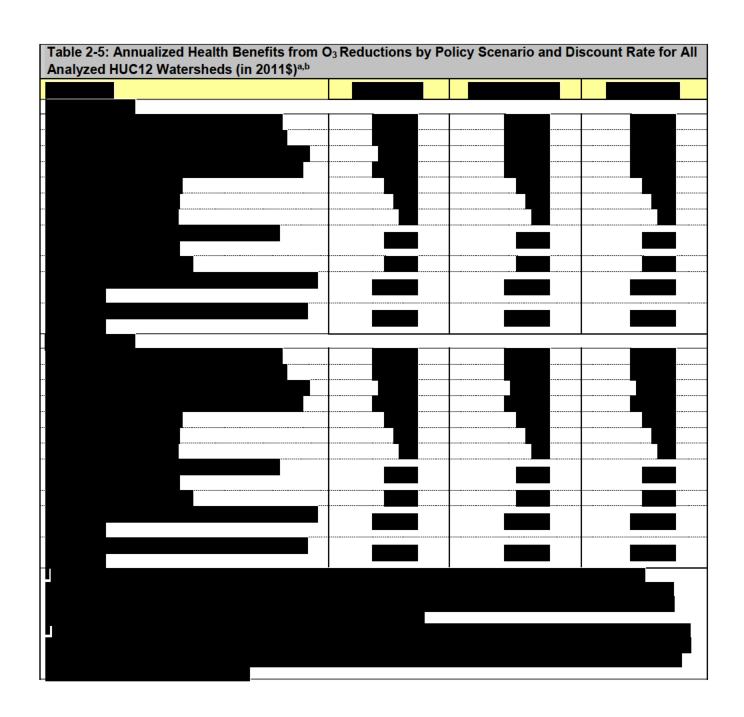


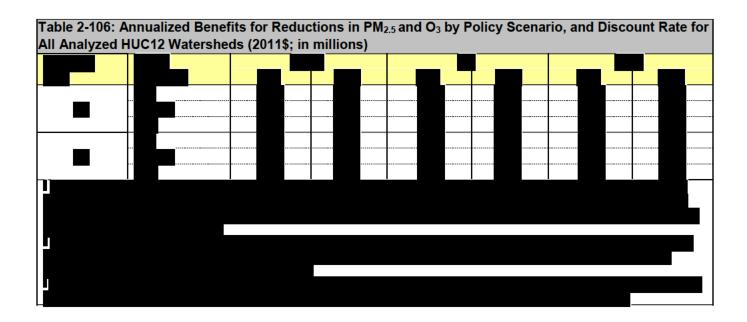






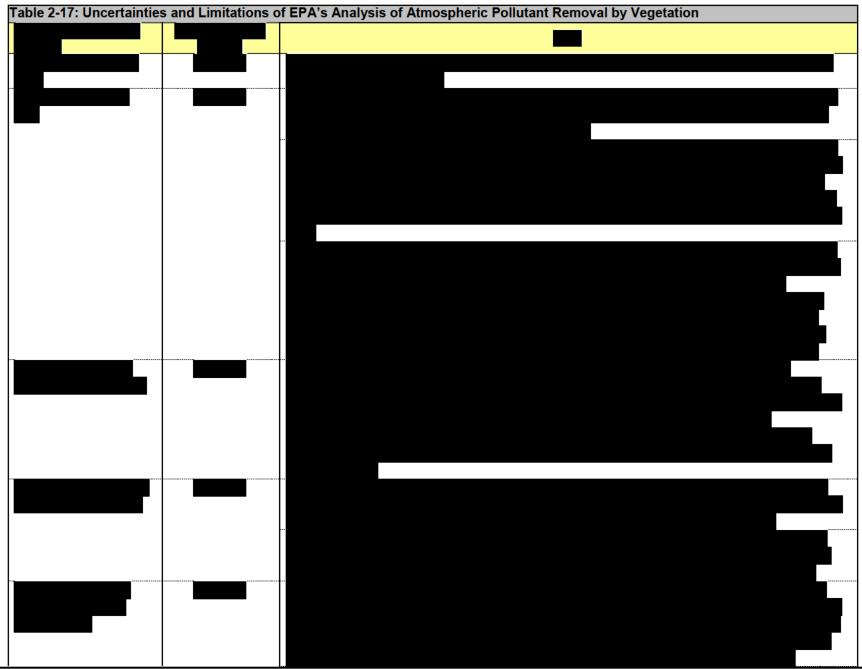


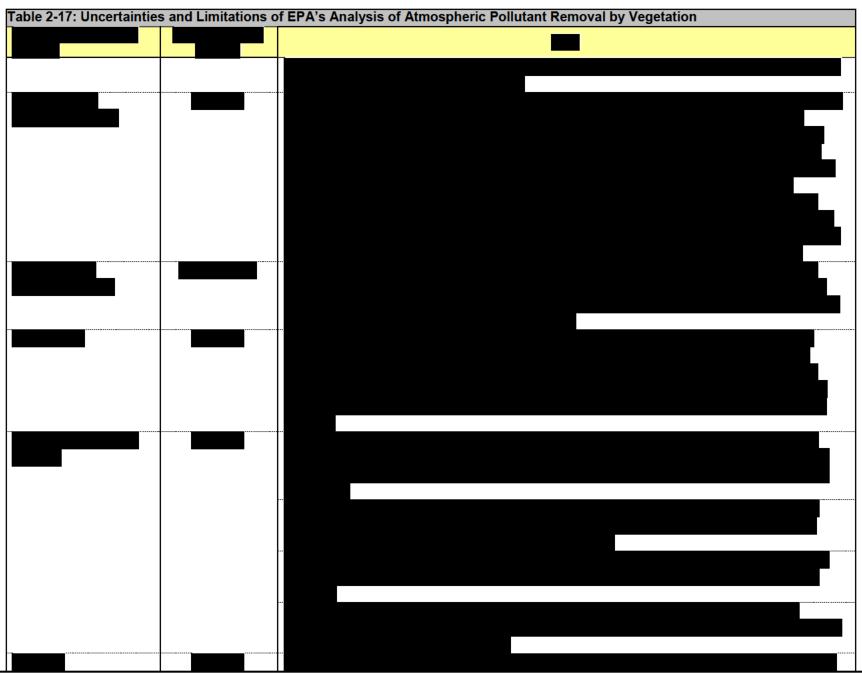


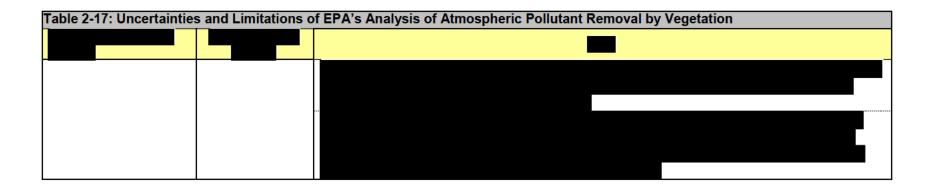


11.3 Uncertainty and Limitations

Table 2-15 below describes uncertainty and limitations inherent in EPA's methodology for the removal of atmospheric pollutants by vegetation.







Abt Associates Inc.

11.4 References

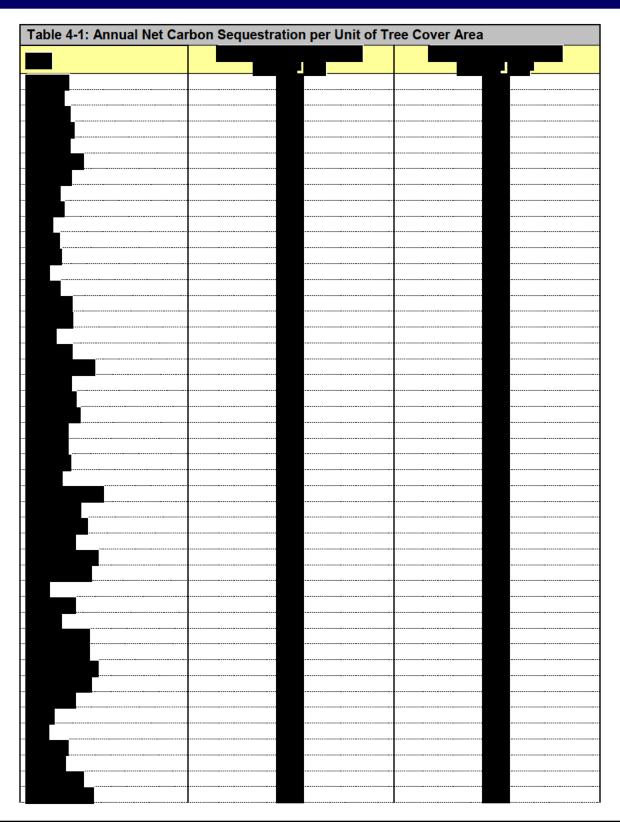
- Agency for Health Care Research and Quality (AHRQ). (2007). HCUPnet, Healthcare Cost and Utilization Project Retrieved October, 2009, from http://hcupnet.ahrq.gov/
- Abt Associates Inc. (2010). BenMAP: Environmental Benefits Mapping and Analysis Program, User's Manual. Bethesda, MD.
- Babin, S. M., Burkom, H. S., Holtry, R. S., Tabernero, N. R., Stokes, L. D., Davies-Cole, J. O., DeHaan, K., & Lee, D. H. (2007). Pediatric patient asthma-related emergency department visits and admissions in Washington, DC, from 2001-2004, and associations with air quality, socio-economic status and age group. *Environ Health*, 6(9).
- Beckett, K. P., Freer-Smith, P. H., & Taylor, G. (2000). Particulate pollution capture by urban trees: effect of species and windspeed. *Global Change Biology*, 6(8), 995-1003.
- Bell, M. L., Dominici, F., & Samet, J. M. (2005). A meta-analysis of time-series studies of ozone and mortality with comparison to the national morbidity, mortality, and air pollution study. *Epidemiology* (Cambridge, Mass.), 16(4), 436.
- Bell, M. L., Ebisu, K., Peng, R. D., Walker, J., Samet, J. M., Zeger, S. L., & Dominici, F. (2008). Seasonal and regional short-term effects of fine particles on hospital admissions in 202 US counties, 1999–2005. *American Journal of Epidemiology*, 168(11), 1301-1310.
- Bell, M. L., McDermott, A., Zeger, S. L., Samet, J. M., & Dominici, F. (2004). Ozone and short-term mortality in 95 US urban communities, 1987-2000. *The Journal of the American Medical Association*, 292(19), 2372-2378.
- Berger, M. C., Blomquist, G. C., Kenkel, D., & Tolley, G. S. (1987). Valuing Changes in Health Risks: A Comparison of Alternative Measures. *Southern Economic Journal*, 53(4), 967-984.
- Burnett, R. T., Smith-Doiron, M., Stieb, D., Raizenne, M. E., Brook, J. R., Dales, R. E., . . . Krewski, D. (2001). Association between ozone and hospitalization for acute respiratory diseases in children less than 2 years of age. *American Journal of Epidemiology*, 153(5), 444-452.
- Cardelino, C., & Chameides, W. (1990). Natural hydrocarbons, urbanization, and urban ozone. Journal of Geophysical Research: *Atmospheres* (1984–2012), 95(D9), 13971-13979.
- Chen, L., Jennison, B. L., Yang, W., & Omaye, S. T. (2000). Elementary school absenteeism and air pollution. *Inhalation Toxicology*, 12(11), 997-1016.
- Dockery, D. W., Cunningham, J., Damokosh, A. I., Neas, L. M., Spengler, J. D., Koutrakis, P., . . . Speizer, F. E. (1996). Health effects of acid aerosols on North American children: respiratory symptoms. *Environmental Health Perspectives*, 104(5), 500.
- Fann, N., Fulcher, C. M., & Hubbell, B. J. (2009). The influence of location, source, and emission type in estimates of the human health benefits of reducing a ton of air pollution. Air Quality, *Atmosphere & Health*, 2(3), 169-176.
- Gilliland, F. D., Berhane, K., Rappaport, E. B., Thomas, D. C., Avol, E., Gauderman, W. J., London, S.J., Margolis, H.G., McConnell, R., Islam, K. T., & Peters, J.M. (2001). The effects of ambient air pollution on school absenteeism due to respiratory illnesses. *Epidemiology*, 12(1), 43-54.
- Glad, J. A., Brink, L. L., Talbott, E. O., Lee, P. C., Xu, X., Saul, M., & Rager, J. (2012). The Relationship of Ambient Ozone and PM2. 5 Levels and Asthma Emergency Department Visits: Possible Influence of Gender and Ethnicity. *Archives of Environmental & Occupational Health*, 67(2), 103-108.
- Harrington, W., & Portney, P. R. (1987). Valuing the benefits of health and safety regulation. *Journal of Urban Economics*, 22(1), 101-112.
- Ito, K., De Leon, S. F., & Lippmann, M. (2005). Associations between ozone and daily mortality: analysis and meta-analysis. *Epidemiology*, 16(4), 446-457.
- Kloog, I., Coull, B. A., Zanobetti, A., Koutrakis, P., & Schwartz, J. D. (2012). Acute and chronic effects of particles on hospital admissions in New-England. *PloS one*, 7(4), e34664.

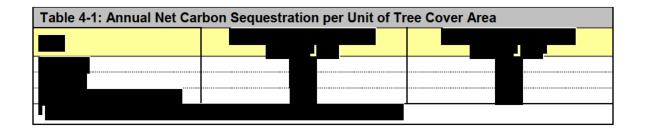
- Kottek, M., Grieser, J., Beck, C., Rudolf, B., & Rubel, F. (2006). World Map of the Köppen-Geiger climate classification updated. *Meteorologische Zeitschrift*, 15, 259-263. Available at: http://koeppen-geiger.vu-wien.ac.at/usa.htm
- Krewski, D., Jerrett, M., Burnett, R. T., Ma, R., Hughes, E., Shi, Y., Turner, M.C., Pope, C.A., Thurston, G., Calle, E.E., & Thun, M. J. (2009). Extended follow-up and spatial analysis of the American Cancer Society study linking particulate air pollution and mortality (pp. 5-114 (discussion 115-136)). Boston, MA: Health Effects Institute.
- Lepeule, J., Laden, F., Dockery, D., & Schwartz, J. (2012). Chronic exposure to fine particles and mortality: an extended follow-up of the Harvard Six Cities Study from 1974 to 2009. *Environmental Health Perspectives*, 120(7), 965.
- Levy, J. I., Chemerynski, S. M., & Sarnat, J. A. (2005). Ozone exposure and mortality: an empiric bayes metaregression analysis. *Epidemiology*, 16(4), 458-468.
- Lovett, G. M. (1994). Atmospheric Deposition of Nutrients and Pollutants in North America: An Ecological Perspective. *Ecological Applications*, 4(4), 630-650.
- Mar, T. F., Koenig, J. Q., & Primomo, J. (2010). Associations between asthma emergency visits and particulate matter sources, including diesel emissions from stationary generators in Tacoma, Washington. *Inhalation Toxicology*, 22(6), 445-448.
- Mar, T. F., Larson, T. V., Stier, R. A., Claiborn, C., & Koenig, J. Q. (2004). An analysis of the association between respiratory symptoms in subjects with asthma and daily air pollution in Spokane, Washington. *Inhalation Toxicology*, 16(13), 809-815.
- McPherson, E., Gregory, E., & Simpson, J. R. (1999). Carbon dioxide reduction through urban forestry: guidelines for professional and volunteer tree planters (pp. 237pp-237pp): U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station.
- Moolgavkar, S. H. (2000a). Air pollution and hospital admissions for chronic obstructive pulmonary disease in three metropolitan areas in the United States. *Inhalation Toxicology*, 12(S1), 75-90.
- Moolgavkar, S. H. (2000b). Air pollution and hospital admissions for diseases of the circulatory system in three US metropolitan areas. Journal of the Air & Waste Management Association, 50(7), 1199-1206.
- Moolgavkar, S. H., Luebeck, E. G., & Anderson, E. L. (1997). Air pollution and hospital admissions for respiratory causes in Minneapolis-St. Paul and Birmingham. *Epidemiology*, 364-370.
- Nowak, D., Hirabayashi, S., Bodine, A., & Hoehn, R. (2013). Modeled PM2.5 removal by trees in ten U.S. cities and associated health effects. *Environmental Pollution*, 178, 395-402,.
- Nowak, D. J. (1994). Air pollution removal by Chicago's urban forest. In E. G. McPherson, D. J. Nowak & R. A. Rowntree, (Eds) (Eds.), Chicago's Urban Forest Ecosystem: Results of the Chicago Urban Forest Climate Project. General Technical Report NE-186 (pp. 63-82). Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station.
- Nowak, D. J. (2010, August 2). [Personal communications during conference call with EPA and Abt Associates regarding application of the U.S. Forest Service models].
- Nowak, D. J., Crane, D. E., & Stevens, J. C. (2006). Air pollution removal by urban trees and shrubs in the United States. *Urban Forestry & Urban Greening*, 4(3-4), 115-123.
- Nowak, D. J., Crane, D. E., Stevens, J. C., & Ibarra, M. (2002). Brooklyn's urban forest. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station.
- Nowak, D. J., & Greenfield, E. J. (2009). Urban and Community Forests of the Mid-Atlantic Region: New Jersey, New York, and Pennsylvania: United States Department of Agricultural, Forest Service, Northern Research Station.
- Nowak, D. J., Hoehn, R. E., III, Crane, D. E., Stevens, J. C., & Walton, J. T. (2006). Assessing urban forest effects and values, Washington, D.C.'s urban forest (pp. 24pp-24pp). Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station.
- Nowak, D. J., McHale, P. J., Ibarra, M., Crane, D. E., Stevens, J. C., & Luley, C. J. (1998). Modeling the Effects of Urban Vegetation on Air Pollution. In S. E. Gryning & N. Chaumerliac (Eds.), Air Pollution Modeling and Its Application XII. New York, NY: Plenum Press.

- Ostro, B., Lipsett, M., Mann, J., Braxton-Owens, H., & White, M. (2001). Air pollution and exacerbation of asthma in African-American children in Los Angeles. Epidemiology, 12(2), 200-208.
- Ostro, B. D. (1987). Air pollution and morbidity revisited: a specification test. *Journal of Environmental Economics and Management*, 14(1), 87-98.
- Ostro, B. D., & Rothschild, S. (1989). Air pollution and acute respiratory morbidity: an observational study of multiple pollutants. *Environmental Research*, 50(2), 238-247.
- Peel, J. L., Tolbert, P. E., Klein, M., Metzger, K. B., Flanders, W. D., Todd, K., . . . Frumkin, H. (2005). Ambient air pollution and respiratory emergency department visits. Epidemiology, 16(2), 164-174.
- Peng, R. D., Bell, M. L., Geyh, A. S., McDermott, A., Zeger, S. L., Samet, J. M., & Dominici, F. (2009). Emergency admissions for cardiovascular and respiratory diseases and the chemical composition of fine particle air pollution. *Environmental Health Perspectives*, 117(6), 957.
- Peng, R. D., Chang, H. H., Bell, M. L., McDermott, A., Zeger, S. L., Samet, J. M., & Dominici, F. (2008). Coarse particulate matter air pollution and hospital admissions for cardiovascular and respiratory diseases among Medicare patients. *Journal of the American Medical Association*, 299(18), 2172-2179.
- Peters, A., Dockery, D. W., Muller, J. E., & Mittleman, M. A. (2001). Increased particulate air pollution and the triggering of myocardial infarction. *Circulation*, 103(23), 2810-2815.
- Pope III, C. A., Dockery, D. W., Spengler, J. D., & Raizenne, M. E. (1991). Respiratory health and PM10 pollution: a daily time series analysis. *American Review of Respiratory Disease*, 144(3 pt 1), 668-674.
- Post, E., Grambsch, A., & et.al. (2011). Climate Change Impacts on Human Health via Changes in Ambient Ozone Concentrations (Submitted to EHP, under 2nd round review).
- Russell, M. W., D.M, H., Drowns, S., Hamel, E. C., & Hartz, S. C. (1998). Direct medical costs of coronary artery disease in the United States. *The American Journal of Cardiology*, 81(9), 1110-1115.
- Schwartz, J. (1994a). Air pollution and hospital admissions for the elderly in Detroit, Michigan. American *Journal of Respiratory and Critical Care Medicine*, 150(3), 648-655.
- Schwartz, J. (1994b). PM10 ozone, and hospital admissions for the elderly in Minneapolis-St. Paul, Minnesota. *Archives of Environmental Health: An International Journal*, 49(5), 366-374.
- Schwartz, J. (1995). Short term fluctuations in air pollution and hospital admissions of the elderly for respiratory disease. *Thorax*, 50(5), 531-538.
- Schwartz, J., & Neas, L. M. (2000). Fine particles are more strongly associated than coarse particles with acute respiratory health effects in schoolchildren. *Epidemiology*, 11(1), 6-10.
- Sheppard, L. (2003). Ambient Air Pollution and Non-Elderly Asthma Hospital Admissions in Seattle, Washington, 1987-1994 (pp. 237-240). Boston, MA.
- Simpson, J. R. (2002). Improved estimates of tree-shade effects on residential energy use. *Energy and Buildings*, 34(10), 1067-1076.
- Slaughter, J. C., Kim, E., Sheppard, L., Sullivan, J. H., Larson, T. V., & Claiborn, C. (2005). Association between particulate matter and emergency room visits, hospital admissions and mortality in Spokane, Washington. *Journal of Exposure Science and Environmental Epidemiology*, 15(2), 153-159.
- Smith, D. H., Malone, D. C., Lawson, K. A., Okamoto, L. J., Battista, C., & Saunders, W. B. (1997). A national estimate of the economic costs of asthma. *American Journal of Respiratory and Critical Care Medicine*, 156(3), 787-793.
- Stanford, R., Mclaughlin, T., & Okamoto, L. J. (1999). The cost of asthma in the emergency department and hospital. *American Journal of Respiratory and Critical Care Medicine*, 160(1), 211-215.
- Taha, H. (1996). Modeling impacts of increased urban vegetation on ozone air quality in the South Coast Air Basin. *Atmospheric Environment*, 30(20), 3423-3430.
- U.S. EPA. (2006). Final Regulatory Impact Analysis: PM2.5 NAAQS. Research Triangle Park, NC: Office of Air and RAdiation, Office of Air Quality Planning and Standards.
- U.S. EPA. (2008). Final Ozone NAAQS Regulatory Impact Analysis. Research Triangle Park, NC: Office of Air and Radiation, Office of Air Quality Planning and Standards.
- U.S. EPA. (2009). Integrated Science Assessment for Particulate Matter. Research Triange Park, NC: National Center for Environmental Assessment- RTP Division, Office of Research and Development.

- U.S. EPA. (2010a). Guidelines for Preparing Economic Analysis: National Center for Environmental Economics, Office of Policy.
- U.S. EPA. (2010b). Our Nation's Air: Status and Trends through 2008. Research Triangle Park, NC: Office of Air Quality Planning and Standards.
- U.S. EPA. (2013a). Air Trends. Available at: http://www.epa.gov/airtrends/index.html
- U.S. EPA. (2013b). Technical Support Document: Estimating the Benefit per Ton of Reducing PM2.5 Precursors from 17 Sectors. Office of Air and Radiation, Office of Air Quality Planning and Standards, Research Triangle Park, NC.
- U.S. EPA. (2013c). Integrated Science Assessment for Ozone and Related Photochemical Oxidants. Research Triangle Park, NC: National Center for Environmental Assessment- RTP Divison, Office of Research and Development.
- USFS. (2011). I-Tree VUE User's Manual v4.0.
- Wilson, A. M., Wake, C. P., Kelly, T., & Salloway, J. C. (2005). Air pollution, weather, and respiratory emergency room visits in two northern New England cities: an ecological time-series study. *Environmental Research*, 97(3), 312-321.
- Wittels, E. H., Hay, J. W., & Gotto, A. M. (1990). Medical costs of coronary artery disease in the United States. *The American Journal of Cardiology*, 65(7), 432-440.
- Woodruff, T. J., Grillo, J., & Schoendorf, K. C. (1997). The relationship between selected causes of postneonatal infant mortality and particulate air pollution in the United States. *Environmental Health Perspectives*, 105(6), 608.
- Yang, J., McBride, J., Zhou, J., & Sun, Z. (2005). The urban forest in Beijing and its role in air pollution reduction. *Urban Forestry & Urban Greening*, 3(2), 65-78.
- Yang, J., Yu, Q., & Gong, P. (2008). Quantifying air pollution removal by green roofs in Chicago. *Atmospheric Environment*, 42, 7266-7273.

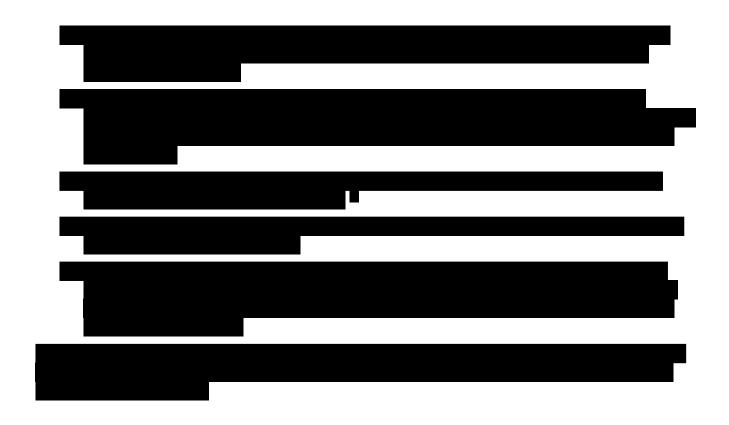
Appendix A. Supplementary material to Chapter 2, Carbon Sequestration.





Appendix B: Additional Detail, PM_{2.5} Health Benefits Estimation





20

